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ENVIRONMENTAL SERVICES INC.

FIELD DEMONSTRATION OF A FULL-SCALE *IN SITU* THERMAL DESORPTION SYSTEM FOR THE REMEDIATION OF SOIL CONTAINING PCBS AND OTHER HYDROCARBONS

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ABSTRACT *A field Demonstration of a full-scale, innovative and cost-effective remediation system using* in situ *thermal desorption (ISTD) was conducted at a state Superfund site in the northeastern United States in early 1996. The Demonstration was performed as part of the regulatory process to obtain a nationwide Toxic Substances Control Act (TSCA) permit for the remediation of soils containing PCBs at concentrations up to 5,000 ppm. An area of approximately 4800 square feet was remediated during six applications of an* in situ *"Thermal Blanket" covering an area of 800 square feet. Each application utilized five 160 square foot, electrically heated, 100-kilowatt modules. The Thermal Blanket heaters were operated at temperatures as high as 925 °C. The modules contain 10" of vermiculite insulation to reduce upward heat losses to less than 10% of total power. The modules are covered with an impermeable silicone sheet and the* in situ *process is run at negative pressure to collect contaminants, prevent contaminant migration and eliminate odors. Off-gas emissions are controlled by a vapor extraction system comprised of a cyclonic separator for particulate removal, a flameless thermal oxidizer for destruction of residual contaminants, and a carbon polishing unit. Treatment times ranged from slightly more than 24 hours to treat the upper six inches to approximately four days to treat soil 12 to 18 inches deep. Temperature profiles and remedial efficiency are consistent with results from a computer thermal simulator. Post-treatment soil samples demonstrated the capability to achieve stringent soil cleanup levels of less than 2 ppm for PCBs (most samples were below the detection limits of EPA Method 8080) while concurrently meeting ambient air quality standards with respect to air emissions and worker exposure limits. The Thermal Blanket is less intrusive than other permanent treatment remedies and produces less noise, generates less dust and has a minimum of other impacts on the surrounding community.*

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INTRODUCTION

Thermal desorption has been recognized as an effective method for the removal of PCBs from soil (1). The Thermal Blanket is an *in situ* thermal desorption technology which was developed by Shell, GE and their contractors for removal of polychlorinated biphenyls (PCBs) or other primarily organic contaminants from surface soils (2,3,4,5). A full-scale field demonstration of this technology was conducted at a former dragstrip site in the northeastern United States between January 9, 1996 and March 3, 1996. Oils containing PCBs had been used for dust control at the dragstrip in the 1960's leaving PCB residuals in the surface soil. The demonstration was conducted on soil containing average PCB concentrations in the treatment zone ranging from 75 to 1,264 ppm and a maximum concentration of 5,212 ppm within the test locations.

The two primary goals of the Demonstration were to show the effectiveness of the full-scale Thermal Blanket system in reducing PCB concentrations in surface soils, *in situ*, and to demonstrate that the system can operate without any adverse impact to human health and the environment.

carbon unit in the event of oxidizer malfunction; noise reduction measures, including a muffler attached to the blower stack and a sound dampening enclosure around the blowers were implemented; an orifice plate was installed to monitor flow from each set of heating modules; the inlet header, cyclone and 14" fume line were insulated to prevent condensation and improve thermal efficiency; and the fresh air inlet duct was extended to recycle waste heat from the heat exchanger.

Process Operating Parameters

The four permit parameters designated to monitor and assure performance efficiency of the Thermal Blanket system included: oxidizer temperature; carbon monoxide concentration in exhaust; flow rate through the system; and vapor temperature at the carbon bed inlet.

The overall effectiveness of the system was later confirmed via the measured PCB concentration in the remediated soil and stack emissions.

Operational Sequence

The Demonstration was conducted on six 800 ft^2 test plots of soil from areas containing average PCB concentrations in excess of 500 ppm. Three duplicate Demonstration tests were performed which involved the sequential heating of two of these test plots. During three alternate test runs, a stack test was performed to monitor the effectiveness of the air emissions control portion of the Thermal Blanket system. A fourth test was conducted to demonstrate the capability to remediate PCBs from deeper regions.

Sampling and Monitoring Procedures

During the Demonstration, environmental and process-related samples and monitoring data were collected in order to demonstrate and evaluate the performance of the Thermal Blanket system, to ensure that PCB emissions to the environment did not impact human health and the environment, and to show that the Thermal Blanket system can be safely used by site personnel.

Soil Sampling for PCB Analysis

Pre-treatment and post-treatment soil samples were collected to meet the following objectives: 1) demonstrate that the technology is capable of removing PCBs from soil to a concentration less than 2 ppm at the treatment depth; 2) determine the quantity of PCBs removed from the soil during the test; 3) show that PCBs removed from the test area are captured and do not migrate to surrounding clean soil; and 4) demonstrate that the technology can remove residual concentrations of PCBs from soil at a depth to 18" below original surface grade.

Pre-Treatment Soil Sampling

During the initial remedial investigation in 1991 and 1992, the site was divided into a grid of 100 foot by 100 foot squares to characterize the distributions of PCBs in the soil. The PCBs were found primarily in the top 6" of soil across the site. The Demonstration tests were conducted in an area which had been delineated as having average PCB concentrations greater than 500 ppm. Pre-treatment samples were collected to verify the average concentration in the test area and determine the concentration variance within the test area.

Five discrete samples were collected in each of six Demonstration test areas prior to treatment by the Thermal Blanket. A shallow (0 to 6") composite was prepared in all six test areas. Shallow (0 to 6") discrete samples and a shallow (0 to 3") composite were analyzed in two test areas. Deep (6" to 12") soil samples were collected in three test areas .

Prior to the fourth test, five discrete samples were collected in the test area. The samples were taken where residual PCBs or deeper contamination were found by post-treatment analytical results after the first three tests. Samples were collected from a 12" to 18" interval below original surface grade, composited in the field laboratory and delivered to the contract analytical laboratory.

Post-Treatment Soil Sampling

After each of the demonstration test runs, post-treatment samples were collected at ten discrete positions in each of the six Demonstration test areas. A shallow (0 to 6") composite was prepared in all six test areas. Additionally, shallow (0 to 6") discrete samples and a shallow (0 to 3") composite were analyzed in two test areas. Deep (6" to 12") soil samples were collected in three test areas.

Additional samples were collected beneath and adjacent to the test areas to determine the potential for desorbed PCBs to migrate and condense in unheated soil, rather than be extracted by the process. After the fourth test, five discrete samples were collected in the test area and composited for three depth intervals: 0-6"; 6-12"; and 12-18". The sample positions corresponded to positions which contained residual PCBs prior to treatment. All samples were split for delivery to an monitored at 16 locations on three levels within the oxidizer bed, and all temperatures at each of the three levels were recorded. Process flows, including heating module flow, propane flow and oxidizer system flow were also monitored using analog meters recorded by the programmable logic controller (PLC). The vacuum at each heating blanket was measured using a magnihelix pressure gauge.

Analytical Procedures

The analytical plan consisted of methods to meet the data quality objectives defined in the Quality Assurance Plan, determine compliance with cleanup goals, adjust process parameters in the field, monitor the ambient air, and characterize waste for disposal. The following analytical methods were applied to meet the data quality objectives: 1) field screening for PCBs by SW-846 Method 4020 (immunoassay testing) for post-treatment soil; 2) confirmatory soil analyses by a contract laboratory by SW-846 Method 8080 with state CLP deliverables; 3) EPA Method 23 for monitoring stack emissions including EPA SW-846 Method 8270 for semi-volatiles; 4) NIOSH Method 5503 for ambient air samples to evaluate compliance with Occupational Safety and Health Administration (OSHA) standards, state guidance, and the site Health and Safety Plan (HASP); and 5) SW-846 Method 8080 to characterize waste containing PCBs for off-site disposal.

SOIL RESULTS

Pre- and post-treatment soil sampling results are summarized in Figure 2. Pre-treatment soil data shows that the overall average PCB concentration in the top 6 inches of the test area averaged 509 mg/kg. Composites from the individual 800 square foot test areas ranged in concentration from 75 to 1264 mg/kg. Individual discrete soil samples ranged from 0.78 to 5212 mg/kg. Although a target treatment depth of 6 inches had been selected based on historical sample results within and around the test area, three of the discrete pre-treatment samples collected in the 6 to 12 inch depth interval also exceeded 2 mg/kg PCB concentration, with a range of 0.032 to 3.050 mg/kg.

Post-treatment soil data in the 0-6 inch depth interval was below 2 mg/kg on a composite average basis in 5 of the 6 test areas. A review of discrete samples showed that the composite sample measuring 3 mg/kg was collected 6 inches inside the edge of a heating module. All other portions of the test area, as represented by discrete samples, were well below 2 mg/kg. In fact, 3 of 6 composite samples in the 0-6" depth interval, and 17 of 20 discrete samples analyzed in this interval had non-detectable PCB concentrations.

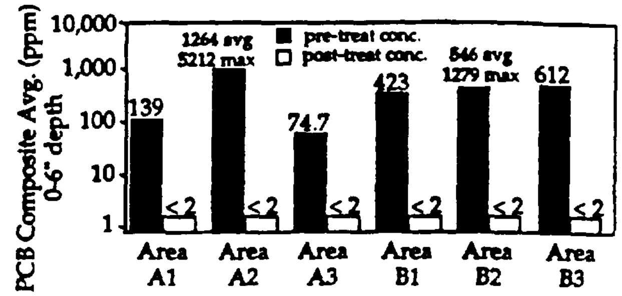

Figure 2. Thermal Blanket soil cleanup results. Cleanup objectives were achieved in each of the six tests in the grids with the highest PCB concentrations. Maximum PCB concentrations are indicated for areas A1 and B2.

This indicates that the overlap of 6 inches between successive placements of the heating modules may not be adequate in more contaminated areas, and suggests that a 1 foot overlap would be appropriate in future operation.

At the conclusion of the test program, the edge effect was quantified through a series of measurements. Specifically, a series of samples was collected at one-foot intervals along a line perpendicular to the outside edge of the treated area. Sample results indicated that all samples located 1 foot or more within the edge of the heating module met the 2 mg/kg treatment standard. The sample at the edge had significantly reduced in concentration, and samples beyond the edge were on the same order of magnitude and variability as pre-test composite samples in the general area as shown in Table 1.

Post-treatment data collected in the 6-12 inch depth range generally showed that PCBs did not migrate vertically during the test. Six out of fifteen of the post test samples in this interval had non-detectable PCB concentrations (< 0.033 mg/kg). For comparison, all fifteen of the pre-test samples had PCBs. This indicates that the reduction in PCB concentration extended even below the targeted treatment depth of 6 inches, as low-level PCB concentrations existing prior to treatment were further reduced. There were three

Table 1. PCB sampling results from horizontal transect extending through and beyond treatment zone at depth of 0" to 6".

Sampling Location	Concentration (ppm)
4 ft. inside zone	< 0.033
3 ft. inside zone	< 0.033
2 ft. inside zone	< 0.033
1 ft. inside zone	0.100
zone edge	96.1
1 ft. outside zone	1582
2 ft. outside zone	840

Ambient Air Testing and Worker Exposure

Ambient air tests conducted for periods of several hours within and immediately downwind of the test area found no detectable PCB concentrations. Personnel air samples were non-detect for PCBs except for one example of a worker moving heating modules between test areas. However, the level detected was far below the current NIOSH standard. This testing, as presented in Figure 6, indicates no hazard to site workers.

PROCESS

The process data recorded during the Demonstration show very stable system operation, with most parameters remaining within fairly narrow ranges during the majority of the tests. This process stability is consistent with previous experience (5).

Thermocouples monitoring the furnace belt heaters exhibited the same time-dependent temperature behavior observed during prior testing (5). Maximum budgeted power is applied to each module and heater temperatures rise rapidly at the beginning of each test, easily keeping up with stepwise manual increases in the control setpoint to approximately 370 °C. Thereafter heater temperatures rise slowly because all the power allotted to each module is efficiently transferred to the soil by radiation, so the heaters themselves cannot get hotter. As the soil temperature increases, heater temperatures rise slowly for several hours until they reach the 870 °C setpoint. Individual heaters generally behave similarly, although their temperatures can diverge somewhat as the soil dries and water content becomes variable in the test area. Heater setpoints are then adjusted to keep the highest temperatures below 980 °C at all times, and generally in the range of 875-925 °C.

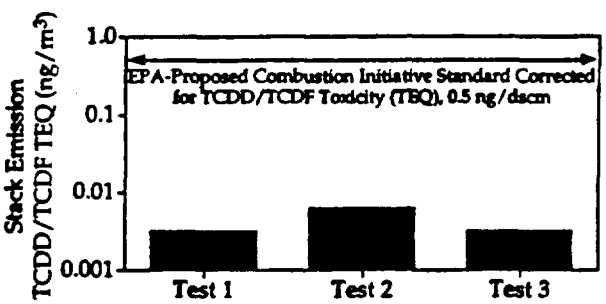

Figure 5. Thermal Blanket PCDD/PCDF emissions expressed as TCDD/TCDF toxic equivalents (TEQ). PCDD/PCDF stack concentrations were orders of magnitude below recently proposed combustion initiative guidelines. Levels at site boundary were orders of magnitude below stack concentrations.

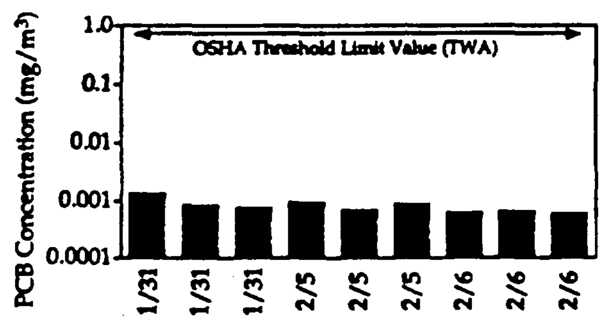

Figure 6. Thermal Blanket PCB ambient air sampling. Site workers' airborne PCB exposures were below detection limits in all but one case and were orders of magnitude below guidelines for occupational exposure.

Soil Temperature

Soil thermocouples also exhibited the anticipated temperature profile, with a gradual increase in temperature up to the boiling point of water, followed by a plateau as the soil moisture was evaporated. Some thermocouples passed this temperature with barely a pause, while others remained at the boiling point for up to 10 hours, indicating differences in soil moisture across the test areas. Thermocouples taking longest to reach temperature tended to be located at the ends of the group of 5 modules, or in low areas which would tend to have greater water infiltration before the test and a greater resultant moisture content. In all test runs soil temperatures at the desired depth were taken up to or beyond the temperature specified in the Demonstration Plan. Effective treatment (i.e. < 2 ppm of PCBs) of the soil was achieved with a temperature at the treatment depth as low as 218 °C. Complete removal (i.e. below detectable levels) was achieved at higher temperatures at the treatment depth.

Process Times

Because of the exponential (Arrhenius) temperature dependence of desorption rates, temperature, rather than time, is the critical parameter which determines successful remediation. (1,5) The time needed to achieve the desired temperature at a selected treatment depth depends on a number of factors similar to those discussed relative to the soil temperature profiles. Therefore, treatment time is only important relative to the economic viability of treating a certain location and is not a critical factor in determining the effectiveness of the system. The target temperature at the 6" treatment depth was usually achieved after 24 hours. Except for one run, blanket power was typically maintained for an additional 12 hours. Effective treatment was achieved in the shorter run which from modules being heated and a similar flow from modules being cooled. The vacuum at the heating blankets was maintained in the range of 2 to 6 inches of water below atmospheric pressure.

DISCUSSION

The primary goal of the Demonstration was to show the effectiveness of the full scale Thermal Blanket system to reduce PCB concentrations in surface soils and to demonstrate that the system can operate in a manner which poses no significant threat to human health and the environment. This goal was successfully attained as follows:

1. All final soil samples collected show the soils within the test area to have a composite PCB concentration below 2 ppm:

- Soils with initial PCB concentrations up to 5212 mg/kgs were treated to concentrations less than 2 ppm, the remedial goal. Soils at least as deep as 18" (in this case, with low PCB concentrations) were also successfully remediated.
- The process was capable of achieving the desired treatment temperature at the target depth (6") after approximately 26 hours of blanket heating. Effective removal of PCBs was achieved with an average soil temperature at the treatment depth as low as 218 °C.
- Soil samples collected below and adjacent to the test area demonstrate that horizontal or vertical migration of PCBs from the test area does not occur.

2. Stack exhaust measurements show that:

- PCB stack emissions (as measured in the exhaust stack) were less than 5% of the applicable state short-term guideline concentration for fenceline air quality;
- Better than 99.99999% of the PCBs entering the treatment system were successfully collected or destroyed; and
- Both total dioxins and toxicity equivalent dioxin were one to two orders of magnitude lower than the very conservative standards proposed in the EPA combustion initiative.

3. Ambient air monitoring for PCBs within and around the work area did not detect any PCBs. Personnel PCB monitoring showed no exposure above the NIOSH standard as presented in the project Health and Safety Plan.

CONCLUSIONS

The Demonstration successfully proved that soils containing PCBs at average levels of 500 ppm and maximum levels up to 5,000 ppm can be successfully treated *in situ* by the Thermal Blanket to below 2 ppm without any adverse impact to public health or the environment. The tests also showed that the PCBs did not migrate away from the Thermal Blanket during treatment. Stack emission measurements yielded PCB levels far below existing or recommended standards and there were no exceedances of existing or recommended worker exposure levels.

REFERENCES

(1) Uzgiris, E.E., W.A. Edelstein, H.R. Philipp, and I.E.T. Iben, "Complex Thermal Desorption of PCBs from Soil." *Chemosphere* 30, 377-387, 1995.

(2) Vinegar, H.J. and G.L. Stegemeier, "Vacuum Method for Removing Soil Contamination Utilizing Surface Electrical Heating." U.S. Patent No. 4,984,594, 1991.

(3) van Egmond, C.F., F.G. Carl, G.L. Stegemeier, and H.J. Vinegar, "Surface Heating Blanket for Soil Remediation." U.S. Patent No. 5,229,583, 1993.

(4) Stegemeier, G.L., and H.J. Vinegar, "Soil Remediation by Surface Heating and Vacuum Extraction." SPE 29771, 1995.

(5) Iben, I.E.T., et. al., "Thermal Blanket for *In Situ* Remediation of Surficial Contamination: A Pilot Test." *Environmental Science and Engineering*, in press, 1996.